AS Unit BY2: Biodiversity and Physiology of Body Systems

Name:	Date:

Topic 2.5 Adaptations for Nutrition – Page 1

2.5 Adaptations for nutrition

(a) The differences between autotrophic and heterotrophic methods of nutrition. The principles of saprotrophic nutrition in Fungi. Secretion of enzymes, external digestion, absorption by diffusion.

(b) Processing food in a tube gut. Ingestion, digestion, absorption and egestion.

(c) The layered structure of the wall of mammalian gut. Regional specialisations of the mammalian gut. Functions of stomach, small intestine and colon.

(d) Adaptations to different diets. Comparison of dentition in a carnivore and a grazing herbivore. Adaptations of herbivore gut to a high cellulose diet. Comparison of the gut regions of herbivore and a ruminant.

Prior to AS you may have done the structure of the human digestive system and the use of enzymes and teeth in the digestion of food. You should also bring in your AS knowledge of enzymes and structures of carbohydrates, lipids and proteins.

		Completed
1.	Go through the PowerPoint in Class	
2.	Be able to give clear distinctions between heterotrophic and autotrophic nutrition.	
3.	Be able to distinguish between holozoic, parasitic and saprotrophic nutrition. Be clear about the main groups of holozoic feeders.	
4.	Label the human digestive system on p8	
5.	Read p9-12 and complete the questions and the summary table on p12	
6.	Read p12-14	
7.	Complete the past paper questions on p15-16	

End of topic checklist for 2.5 Adaptations for Nutrition

Tick as appropriate:

RED: I do not know about this

AMBER: I have heard about this but have not learned this yet. I am unsure on this.

GREEN: I have heard about this and I have learned this. I am confident about this.

Topic	RED	AMBER	GREEN
1. Autotrophs use simple inorganic materials to manufacture complex organic compounds whereas heterotrophs consume complex organic food material.			
2. There are a number of different types of heterotrophic nutrition.			
3. An important group are the saprophytes or saprobionts, which include all bacteria and some fungi.			
4. They feed by secreting enzymes onto food material outside the body and then absorb the soluble products across the cell membrane by diffusion. This is known as extracellular digestion.			
5. In heterotrophs food is processed as it passes along the gut.			
6. In simple organisms, on only one type of food, the gut is undifferentiated.			
7. In more advanced organisms, with a varied diet, the gut is divided into various parts along its length and each part is specialised to carry out particular functions.			
8. These processes are ingestion, digestion, absorption and egestion.			
9. The gut wall consists of four tissue layers surrounding a central cavity – serosa, longitudinal muscle layer, circular muscle layer, submucosa and mucosa.			
10. The human alimentary canal consists of buccal cavity, tongue, salivary glands oesophagus, stomach, duodenum, ileum, colon, rectum, anus and associated organs; liver and pancreas.			
11. There are number of different glands that produce digestive secretions.			
12. Some of these glands are found in the wall of the gut with the secretions passing directly into the gut cavity.			
13. Other glands are found outside the gut with the secretions passing along ducts into the gut cavity.			
14. Organisms with a varied diet require more than one type of enzyme to carry out the digestion of the different food substrates and usually more than one type of enzyme is needed for the complete digestion of a particular food.			
15. Carbohydrate digestion involves the enzyme amylase, which hydrolyses the polysaccharide starch, into the disaccharide maltose. Another enzyme maltase breaks down maltose to glucose.			
16. Proteins are broken down by peptidases into polypeptides, then into single units called amino acids. Endopeptidases hydrolyse peptide bonds within the protein molecule; the peptide bonds at the ends of these short lengths are hydrolysed by exopeptidases.			
17. Fats are broken down into glycerol and fatty acids by just one enzyme, lipase.			
18. The specialised regions of the mammalian digestive system have different pH's therefore the enzymes have different pH optima.			
19. Mucus secretions lubricate food as it passes along the gut and also protects the gut wall.			
20. Absorption of the end products of digestion takes place in the ileum the surface area of which is covered by villi and microvilli.			
21. Glucose and amino acids are absorbed by diffusion and active			

transport into capillaries and then travel via the hepatic portal vein to the liver.			
22. Fatty acids and glycerol are passed into the lacteal, then through the lymphatic system to the blood stream opening at the thoracic duct.			
23. Most water is reabsorbed along with the soluble nutrients in the small intestine. The colon absorbs the remaining water, together with vitamins (secreted by microorganisms in the colon) in order to produce solidified faeces.			
24. Residues of undigested cellulose, bacteria and sloughed cells pass along the colon to be egested as faeces.			
25. Cellulose fibre is required to provide bulk and stimulate peristalsis.			
26. Glucose is absorbed from the blood by cells for energy release in respiration, and any excess is converted to fat for storage.			
27. Amino acids are absorbed for protein synthesis; excess cannot be stored so are deaminated whereby the amino groups are converted to urea and the deaminated remainder is converted to carbohydrate and stored.			
28. Lipids are used for membranes and hormones, and the excess is stored as fat.			
29. Teeth are used in mechanical digestion in order to increase the surface area for enzyme digestion.			
30. Mammals have evolved different types of teeth with each type being specialised for a different function, incisors, canines, premolars and molars.			
31. There are differences between the teeth of carnivores and herbivores reflecting their different diets.			
32. In herbivores their jaw moves in a horizontal plane whereas in carnivores the jaw moves vertically.			
33. The gut of a carnivore is short reflecting the ease with which protein is digested.			
34. Ruminants such as cow and sheep eat mainly grass, a large proportion of which consists of cellulose cell walls.			
35. Ruminants have a specialised stomach or rumen in which mutualistic bacteria live.			
36. The presence of these bacteria together with their modified gut enables ruminants to achieve a more complete breakdown of cellulose.			

Modes of Nutrition

All cells need energy. All living organisms need food in order to obtain energy; the process of obtaining food is called nutrition. There are two types of nutrition, **autotrophic nutrition** and **heterotrophic nutrition**.

Autotrophic Nutrition
Autotrophs are able to manufacture complex organic compounds from simple molecules such as carbon dioxide and water. The manufacture of complex organic molecules from simple molecules requires huge amounts of energy; there are two main groups of autotrophs distinguished depending on their source of energy.

- **Chemoautotrophs** – certain bacteria obtain the energy required to combine carbon dioxide and water from the oxidation of various inorganic materials such as hydrogen sulphide, ammonia, nitrites and iron(III). This method of synthesis is called **chemosynthesis**.
- **Photoautotrophs** – Include green plants, some protoctists and certain bacteria synthesise their complex organic compounds using light energy. This method of synthesis is called **photosynthesis**.

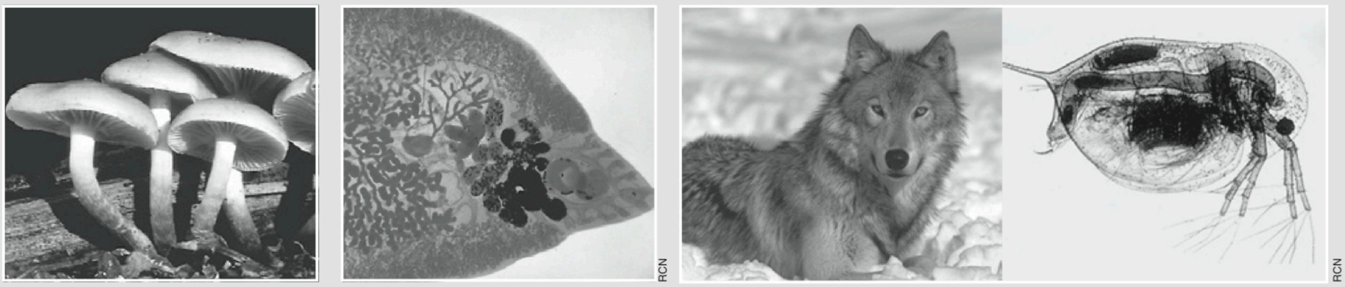
Autotrophic Nutrition

Photoautotrophs: Photosynthetic bacteria, cyanobacteria, algae, plants.

Chemoautotrophs: Sulfur, iron, hydrogen, and nitrifying bacteria.

Heterotrophic Nutrition
This involves taking in complex organic molecules and then breaking them down into simpler molecules that are absorbed into the body. This process of breaking down complex organic molecules into simpler molecules is called **digestion**. Heterotrophs are often referred to as consumers.

Organisms that are heterotrophs can be further broken down into three categories, **saprophytes**, **parasites**, and **holozoic feeders**. **Saprotrophs** such as fungi feed exclusively on dead and decaying material. **Parasites** such as tapeworms and head lice obtain their food from the living body of another organism and **Holozoic feeders** take in solid organic material into their bodies where it is digested.



Most fungi and many bacteria are saprophytes (also called saprotrophs). They are decomposer organisms feeding off dead or decaying matter.

Parasites, e.g. flukes, live on or within their host for much or all of their life. Bacteria, fungi, protoctists, and animals all have parasitic representatives.

Holozoic means to feed on solid organic material from the bodies of other organisms. It is the main feeding mode of animals, although a few specialised plants may obtain some nutrients this way. Holozoic animals are classified according to the form of the food they take in: small or large particles, or fluid.

(Saprotrophs used to be known as saprophytes, but "-phyte" refers to a plant and neither fungi nor bacteria are plants, so saprotrophs or saprobes are the terms now used to describe these organisms. WJEC refers to the older term saprophyte!)

Saprophytic Nutrition

All fungi lack chlorophyll and are **heterotrophic**, absorbing nutrients by direct absorption from the substrate. Many are **saprophytic** (also called saprobiontic or saprotrophic), feeding on dead organic matter, although some are parasitic or live in a relationship with another organism (mutualistic). Parasitic fungi are common plant pathogens, invading plant tissues through stomata, wounds, or by penetrating the epidermis. Mutualistic fungi are very important: they form lichens in association with algae or cyanobacteria, and the mutualistic mycorrhizal associations between fungi and plant roots are essential to the health of many forest plants. Saprophytic fungi, together with bacteria, are the major decomposers of the biosphere. They contribute to decay and therefore to nutrient recycling. Like all fungi, the body is composed of rapidly growing filaments called **hyphae**, which are usually divided by incomplete compartments called **septa**. The hyphae together form a large mass called a **mycelium** (the feeding body of the fungus). The familiar mushroom-like structures that we see are the above-ground reproductive bodies that arise from the main mycelium. The nutrition of a typical saprophyte, *Rhizopus*, is outlined below.

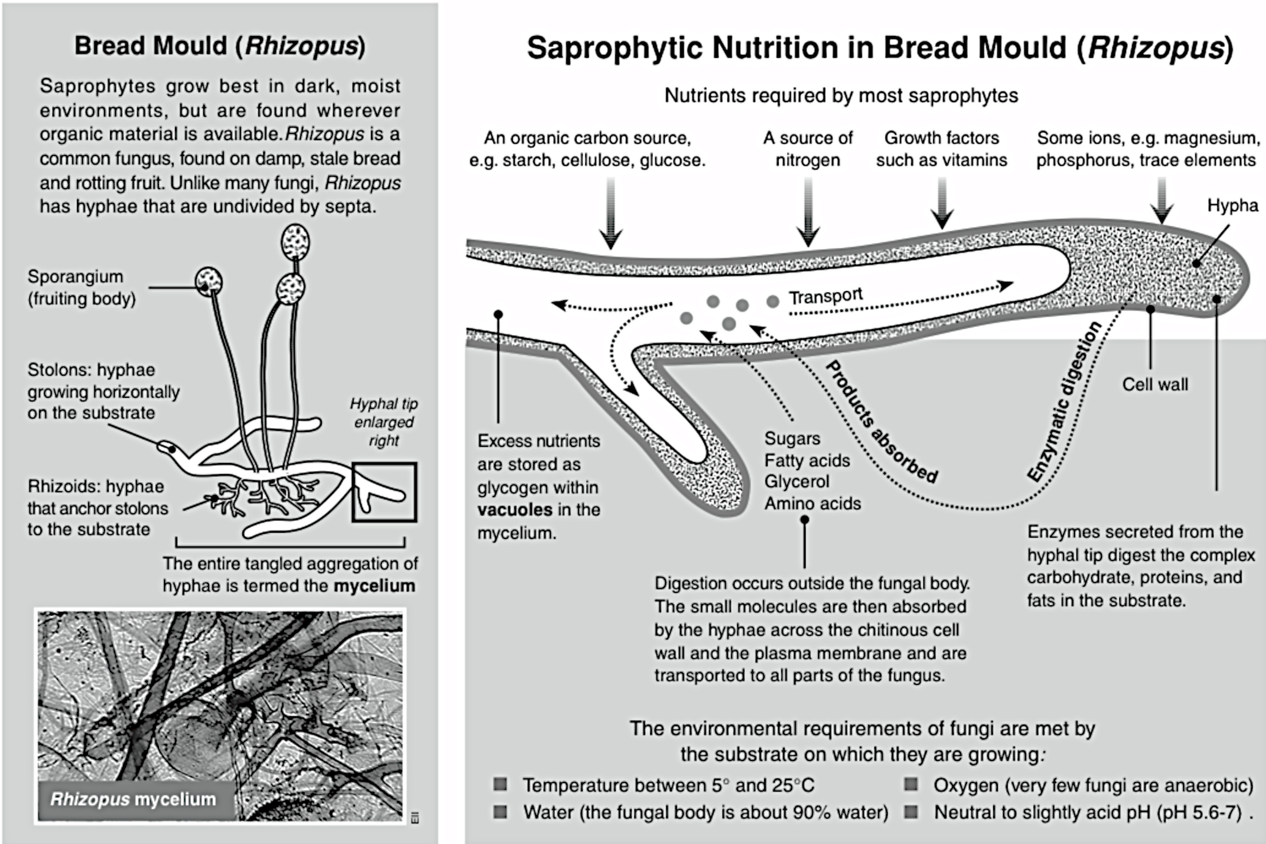


Fig. 1

Saprophytes include all fungi and some bacteria. Microscopic saprophytes are usually referred to as decomposers and they play a vital role in nutrient cycles.

The structure of *Rhizopus* is shown in Fig. 1. The stolons of *Rhizopus* enable the mycelium to spread over the surface of the bread enabling the rhizoids to penetrate the greatest possible volume of bread. The rhizoids synthesize digestive enzymes and secrete them, via golgi vesicles, from their tips into the bread. These enzymes hydrolyse the complex substances in the bread into simple products which are absorbed back into the rhizoids. The enzymes include:

- **Amylases** which hydrolyse starch into maltose sugar.
- **Maltase** which hydrolyses maltose into glucose.
- **Proteases** which hydrolyse proteins into polypeptides.
- **Exopeptidases** and **endopeptidases** which hydrolyse polypeptides into amino acids.
- **Lipases** which hydrolyse fats or oils into fatty acids and glycerol.

The products of digestion are absorbed into the rhizoids, primarily by diffusion, although facilitated diffusion and active uptake may be involved when diffusion gradients are small. Normally there will be a much higher concentration of digestive products in the bread than in the rhizoids. Salts will also be absorbed and water will be taken up by osmosis. The absorbed substances will then be assimilated in the fungal hyphae. *Rhizopus* stores surplus glucose as glycogen.

Features of saprobiontic fungi which enable their continued survival

Saprobiontic fungi must be able to:

- maintain survival and spread through the substrate they are feeding on,
- disperse to new distant suitable substrates and become established on these, and
- be able to survive during adverse conditions (lack of food, lack of water, adverse temperature or pH)

Saprobiontic fungi thus have the following features:

- fungal hyphae grow from their tips and branch frequently. They thus spread through the substrate into untapped food areas and grow away from areas where they have shed excretory waste (negative chemotropism).
- under good growth conditions fungi have very prolific powers of asexual reproduction, producing millions of light spores. These are usually dispersed widely by air currents. If a spore lands on a suitable substrate it can germinate to produce a new hypha. This hypha will use the food reserves in the substrate to grow and divide throughout the new substrate.
- When conditions become adverse, fungi reproduce sexually, producing resistant zygospores. These remain dormant and have a thick protective wall (usually made of calcium oxalate crystals) which protects them until suitable growth conditions are encountered. They can be dispersed widely by air currents. When a zygospore lands on a suitable substrate, providing water, a suitable temperature and a suitable pH is present, the zygospore will germinate to form a new hypha. This often immediately develops an asexual sporangium and asexual spores are released. The new hypha grows and branches throughout the new substrate.

Parasites
A parasite is an organism that feeds from another living organism for most of its life cycle. The parasite benefits as it obtains most of its metabolic requirements, but the host is usually harmed. A successful parasite will minimise the harm so that it can continue to use the host for a longer period of time.

Endoparasites live inside the body of their host; ectoparasites live outside. We will be studying one particular endoparasite, the tapeworm in some detail in the next booklet.

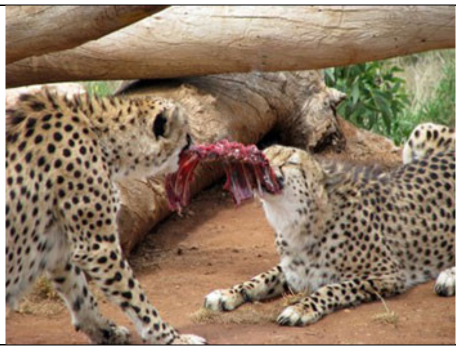
Examples of Endoparasites:

		
Tapeworm	**Roundworms**	**Eyeworm**

Examples of Ectoparasites

		
Ticks	**HeadLice**	**Body Fleas**

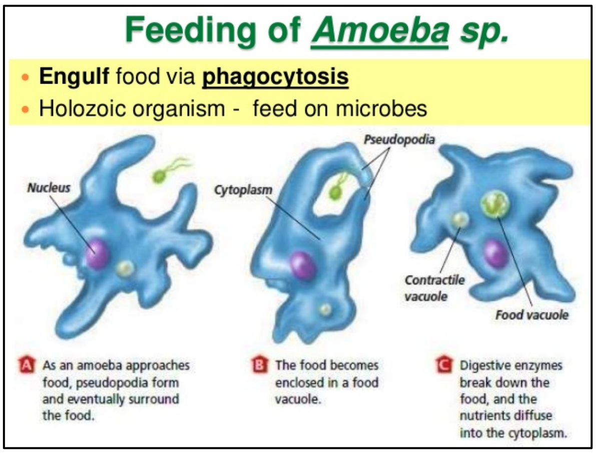
Holozoic Feeders
These include nearly all animals. They ingest food and then digest it. Most animals will have a specialised digestive system where this takes place. The digested food will be absorbed and assimilated into the body. They fall into three main categories:

		
Herbivores which feed primarily on plant materials	Carnivores which feed primarily on other animals	Detritivores which feed on dead and decaying material

Distinguish between a saprotrophs and a detritivore

Heterotrophic Nutrition
Most of the organic molecules from which organisms are made are large and complex. Such molecules are unable to pass through cell surface membranes. All heterotrophs release enzymes, which speed up the breakdown of organic molecules into smaller components, which can pass through cell surface membranes.

Not many organisms carry out intracellular digestions but one example is the amoeba.



Many animals digest their food completely before taking it into the cells. This is called **extracellular** digestion and the gut is where it usually takes place. The gut is a long, narrow, hollow and muscular tube that is organised to allow the movement of its contents in one direction. In simple organisms which intake only one type of simple food the gut will be undifferentiated (no separate compartments are needed to breakdown and deal with different macromolecules). However, in organisms with a varied diet the gut is divided into various parts with each part being specialised for the following functions:

Ingestion: This is taking in food. In humans food is taken into the mouth and chewed.

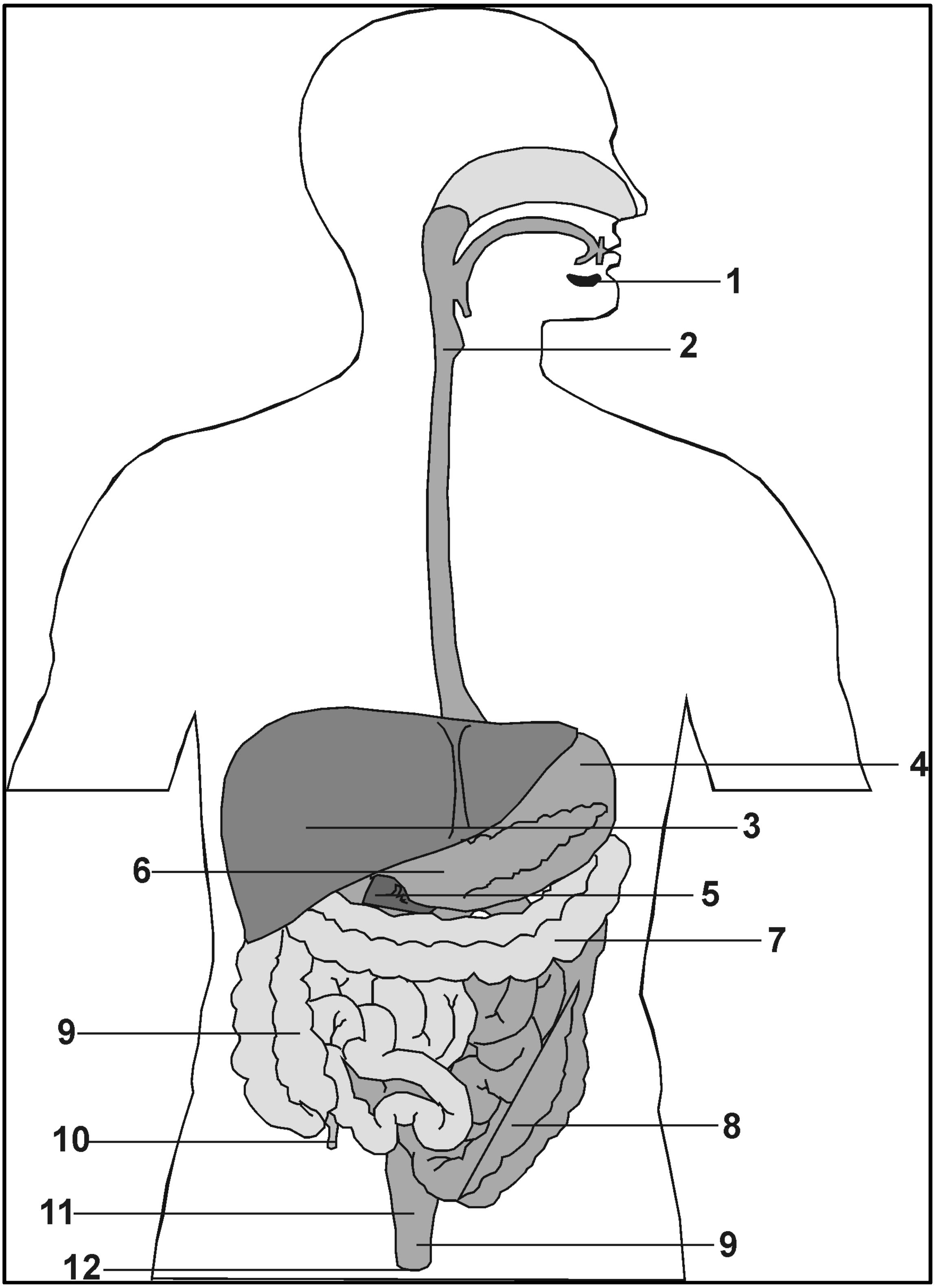
Digestion: The breaking down of large complex molecules using mechanical digestion, chewing and churning and chemical digestion with digestive enzymes.

Absorption: This is the passage through the gut wall into the bloodstream of simple food molecules such as amino acids, sugars and fatty acids, vitamins, minerals and water.

Egestion: The removal of undigested food material from the body.

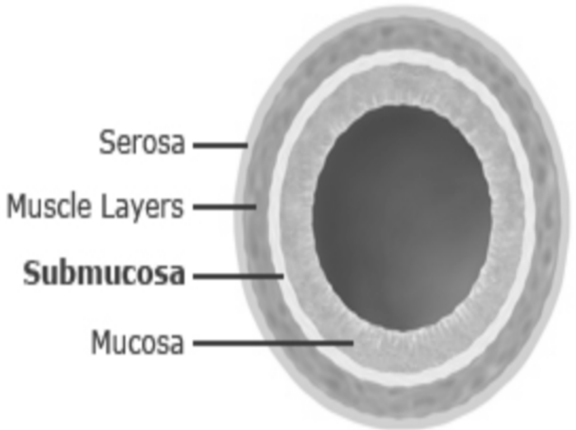
The Gut or Alimentary Canal
This is a continuous muscular tube running from the mouth to the anus. In adults it is about 10m long and is subdivided into organs. The gut is also associated with accessory structures such as salivary glands, liver, gall bladder and pancreas. These lie outside the alimentary canal and will either produce or store secretions, which help with the digestion of food.

Make sure the following are labelled onto the diagram below: buccal cavity / tongue / salivary glands / oesophagus / stomach / duodenum / ileum / colon / rectum / anus / liver and pancreas.



Structure of the Gut Wall

Consists of four different layers of tissue: The mucosa, submucosa, longitudinal and circular muscles and the serosa.



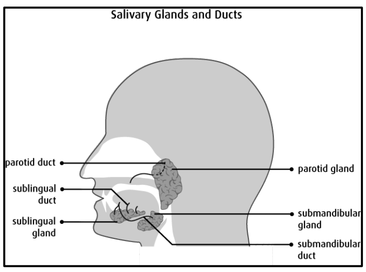
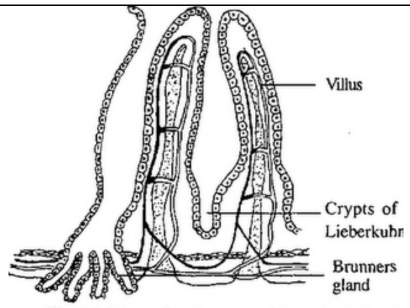
Mucosa: The innermost layer has an epithelium that produces mucus. The mucus protects the intestine wall by lubricating the passage of food, therefore reducing friction and providing a barrier against damaging chemicals. The epithelium of the mucosa also secretes hormone and digestive enzymes in different regions of the gut as well as acting as an absorptive layer.

Submucosa: Contains a rich supply of blood and lymph vessels, which will carry absorbed nutrients away.

Muscle: Contains longitudinal and circular muscles which contract and relax to bring about peristalsis.

Serosa: Has a layer of connective tissue that protects the gut from friction with other organs in the abdomen.

Chemical Digestion of Food Using Enzymes
There are a number of structures called glands that produce digestive secretions such as enzymes; hydrochloric acid and hydrogen carbonate ions. Some glands are found in the wall of the gut with secretions passing directly into the gut cavity whilst others are outside the gut and pass the secretions along ducts.

	 Fig 3.3.1 b_2 : Duodenum and intestinal glands
Salivary Glands – these are ducted.	**Brunners Glands** found in the wall of the gut

Glands found in **mouth** are known as **salivary glands** and produce amylase, mucus, hydrogencarbonate ions and mucus.

Glands found in the **stomach wall** are known as **gastric glands** and they produce water, mucus, HCl, pepsin and rennin.

Glands found in the **pancreas** are known as **pancreatic glands** and they produce water, hydrogencarbonate ions, amylase, trypsin, peptidases, lipase and nuclease.

Glands found in the **small intestine** are referred to as **Brunner's glands** and the **crypts of Lieberkuhn**, they produce water, alkaline salts, enteropeptidase and mucus.

Food is hydrolysed into smaller molecules by enzymes produced by ducted glands or by enzymes immobilised onto the cells of the gut wall. A varied diet will require a range of different enzymes to complete the hydrolysis of the ingested food.

Starch → (amylase) → Maltose → (maltase) → Glucose

Lipids → (Bile salts) → Emulsified lipids → (lipase) → Fatty acids and glycerol

Nucleic acids → (nuclease) → Nucleotides → (nucleotidase) → Pentose, purines, pyrimidine & Pi

Proteins → (endopeptidase) → Polypeptides → (exopeptidase) → Dipeptides → (dipeptidase) → Amino acids

Proteases
There are two groups of proteases:

- Endopeptidases speed up the hydrolysis of peptide bonds within the protein molecules
- Exopeptidases act on terminal peptide bonds (those at the ends of the polypeptide chains)

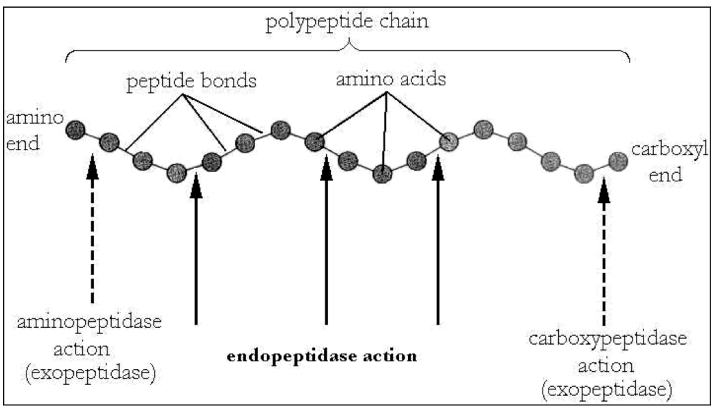
Hydrolysis involving endopeptidases results in proteins being broken down into short polypeptide chains (figure 1.20). Pepsin, trypsin and chymotrypsin are endopeptidases, each only capable of hydrolysing specific peptide bonds.

Pepsin, trypsin and chymotrypsin are secreted into the alimentary canal in their inactive forms: pepsin as pepsinogen, trypsin as trypsinogen and chymotrypsin as chymotrypsinogen. This ensures that these enzymes are activated only when there is food-requiring digestion in the alimentary canal and prevents the enzymes damaging the cells in which they are produced.

Pepsinogen is converted to pepsin by the action of hydrochloric acid in the stomach. Once some pepsin has been formed, it will bring about the conversion of more pepsinogen to pepsin. Trypsinogen is converted to trypsin by the action of the enzyme enterokinase, which is secreted in the ileum, and chymotrypsinogen is activated by trypsin.

The action of exopeptidases results in the breakdown of the short polypeptide chains by the removal of amino acids. There are two kinds of exopeptidases:

- Aminopeptidases hydrolyse peptide bonds at the amino end of a polypeptide chain
- Carboxypeptidases hydrolyse peptide bonds at the carboxyl end of a polypeptide chain
- Protein digestion begins in the stomach, where the optimum pH for hydrolysis by pepsin is 1.5 to 2.0. Here the proteins and long polypeptide chains are broken down to shorter polypeptides. In the duodenum and ileum, where the pH is alkaline, trypsin and chymotrypsin from the pancreatic juice hydrolyse the proteins to shorter polypeptides. Carboxypeptidases are present in the pancreatic juice and their action results in the production of amino acids. Aminopeptidases are present on the microvilli of the epithelial mucosa.



1. What is hydrolysis?

2. How do endo and exopeptidases differ?

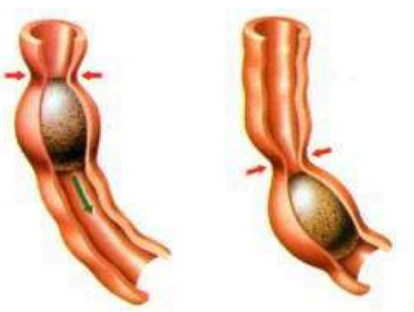
3. Why are peptidases secreted as inactive forms?

4. Suggest why pepsinogen becomes activated in a low pH:

Regions of the Gut (Alimentary Canal)

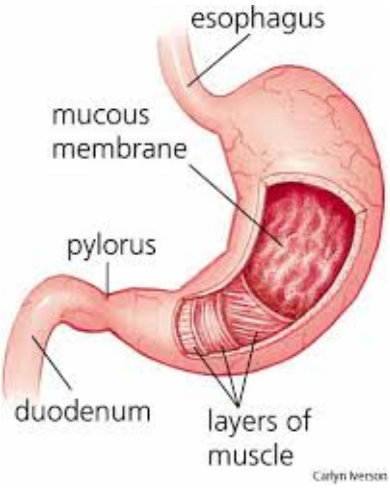
The Buccal Cavity

Mechanical digestion brought about by the chewing of food breaks the food into small particles. It is mixed with saliva. Saliva has a pH of 6.5-7 that consists primarily of water and mucus that softens and lubricates the food for swallowing. Saliva contains an enzyme amylase, which starts digestion of starch; chloride ions in the saliva activate the amylase.



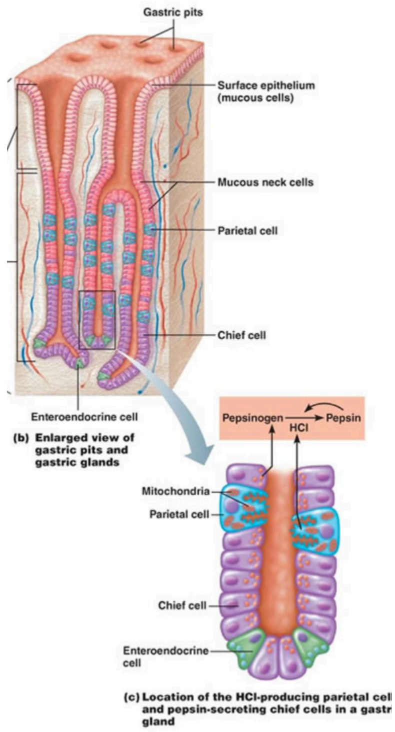
After chewing the food is formed into a bolus (round lump) by the action of the tongue and then swallowed. Peristalsis pushes the bolus down the esophagus to the stomach.

The Stomach



The stomach is a dilated part of the gut where the food remains for up to two hours or more. The mucosa in the stomach wall is indented to form gastric pits. The cells in the pits secrete hydrochloric acid and pepsinogen. The acid activates the conversion of pepsinogen into active pepsin. The acid also provides the optimum pH condition for the pepsin; it also kills most bacteria found on the food and inactivates the salivary amylase.

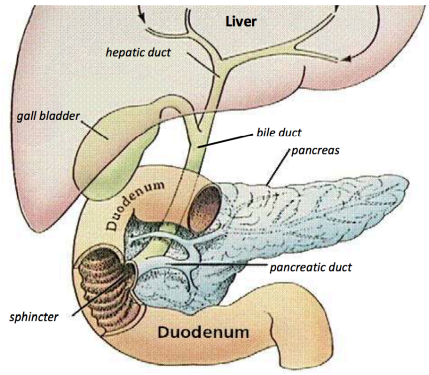
The stomach wall is protected form the affects of pepsin and hydrochloric acid by a thick layer of mucus produced by goblet cells.



Over a few hours the muscular contractions of the stomach wall will churn the food, mixing it with the gastric juices turning it into a semi-liquid called chyme. This chyme will pass into the small intestine in small amouns through the pyloric sphincter.

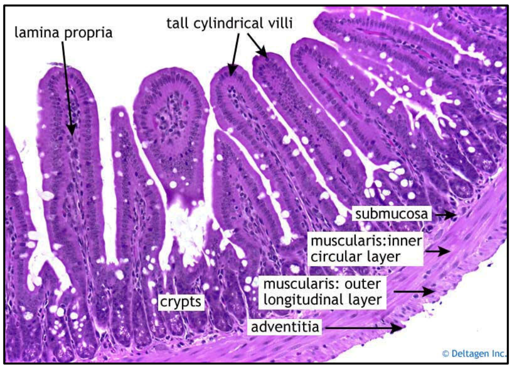
The Small Intestine

The small intestine is divided into two main regions, the duodenum and the ileum. The duodenum comprises the first 20 cm of the small intestine.



The duodenum receives secretions from the liver and the pancreas.

Bile produced by the liver but stored in the gall bladder releases its secretions into the duodenum. Bile emulsifies fats, it lowers the surface tension of fat droplets causing them to break up into lots of little droplets – this helps lipase carry out digestion of this hydrophobic molecule. Bile also contains sodium hydrogencarbonate ($NaHCO_3$), which helps to neutralize the acid from the stomach.



There are deep folds in the wall of the duodenum called crypts of Lieberkuhn, these secrete an alkaline fluid and mucus.

The pancreas produces a fluid called pancreatic juice. This also contains sodium hydrogencarbonate that helps to neutralize stomach acid. It also contains a number of enzymes:

- **Pancreatic amylase**, which hydrolyses any remaining, starch.
- **Pancreatic lipase**, which hydrolyses lipids into fattys acids and glycerol.
- **Endopeptidases**, which hydrolyse proteins into peptides.

In addition to these enzymes, which are secreted by the pancreas, the epithelial cells of the small intestine have enzymes embedded within their cell surface membranes and in their cytoplasm. Thus, digestion occurs outside these cells, at their cell surface membranes and inside the cytoplasm.

- **Maltase** is found within the cytoplasm of epithelial cells and completes the digestion of maltose inside the epithelial cells.
- **Endo and Exopeptidases** also are immobilised and complete the digestion of polypeptides to amino acids

Complete the table below to help summarise enzymatic digestion:

Secretion	Enzymes produced	Site of production	Site of activity	pH	Substrate	Products
Saliva		Salivary glands			Starch	
	Peptidase		Stomach	1.5-2		Polypeptides
Pancreatic Juice	Endopeptidase					
	Amylase		Duodenum	7.0		
	Lipase					
		Intestinal Epithelial Enzymes				
	Endo and Exopeptidases					

Absorption

This takes place in the part of the small intestine referred to as the ileum. The structures responsible for the absorption of food are the **villi**.

What types of molecules will be absorbed in the ileum?

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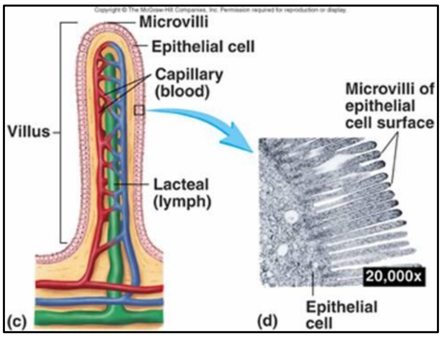

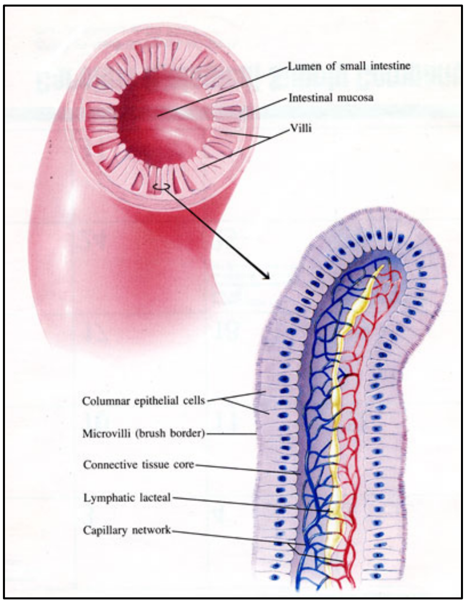

Using the pictures describe how the surface of the ileum is adapted for its role in absorption?

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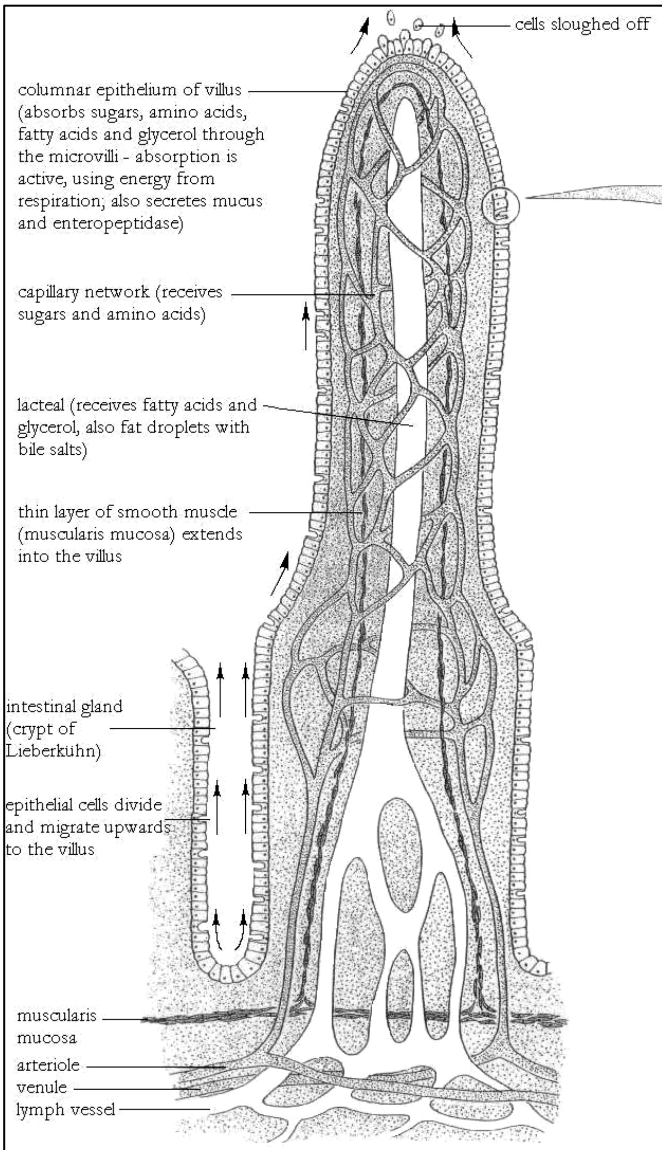
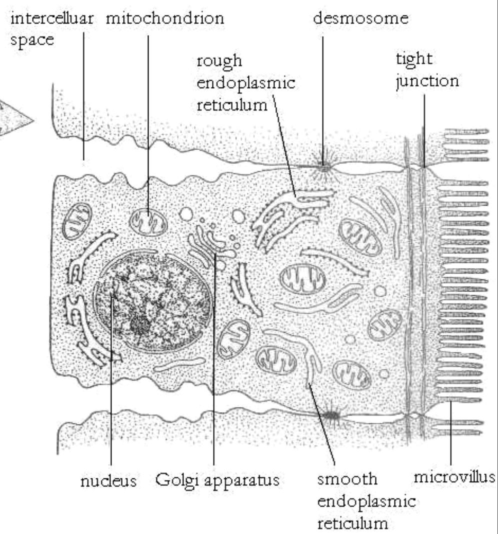
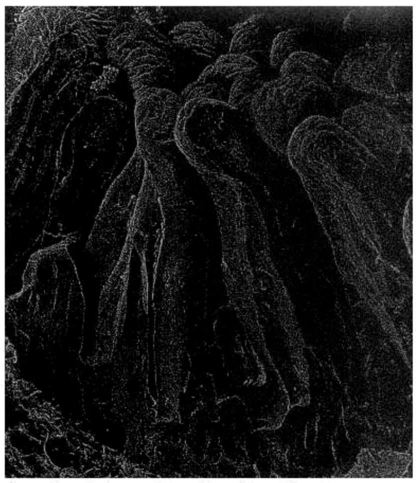






the site of absorption: the villi on the inner surface of the small intestine (X50)

Most of the products of digestion are reabsorbed through the epithelium into the blood capillaries.

- **Glucose** and **Amino Acids** are absorbed by a combination of facilitated diffusion and active transport into the epithelial cells and then into the blood capillaries of the villus.

- The products of **lipid digestion** however are absorbed as micelles into a special network of vessels called a lacteal. The lacteal forms part of the lymphatic system. The fluid in this system is called lymph and components of the lymph can empty into the bloodstream at the thoracic duct.

All of the thousands of tiny capillaries in the ileum eventually join up to form a large blood vessel called the **hepatic portal vein**. This vein takes blood to the liver for processing – further modification, breakdown and storage of some biomolecules. Some of the glucose form carbohydrate digestion is converted into glycogen and stored in the liver.

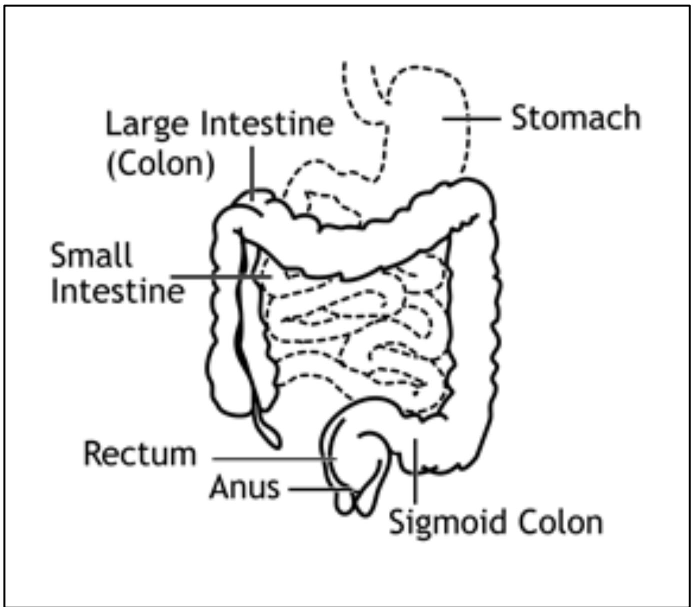
Most of the digested food molecules are distributed around the body for energy and as building blocks for growth and repair. This process is called **assimilation**.

Glucose is transported by the blood and used by body cells in the process of aerobic respiration. Excess glucose is converted into glycogen in the liver and later into fat.

Amino acids are absorbed for protein synthesis, which takes place inside body cells. Excess amino acids cannot be stored and are deaminated, the amine group is removed and converted into urea and the reminder is converted into a carbohydrate and stored.

Lipids will be used for the manufacture of steroid hormones, phospholipids etc. any excess will be stored as fat.

Large Intestine



Its principal function is to absorb remaining water from the waste products of digestion as it compacts the accumulated waste for elimination by defecation.

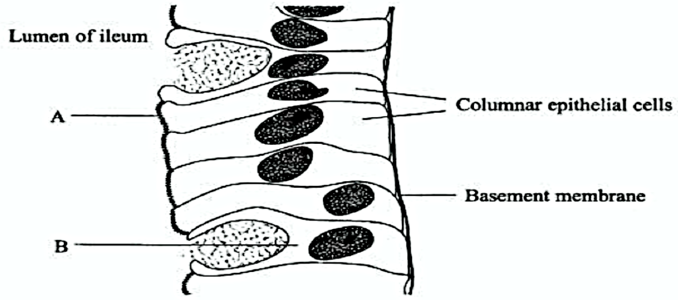
Inorganic salts, vitamins and water are absorbed in the colon. By the time it reaches the rectum indigestible food is in a semi-solid state ready to be egested through the anus as faeces. This process is called defecation and is facilitated by the lubricating effect of large amounts of mucus secreted by goblet cells lining the rectum.

In addition to undigested food faeces also contains cellulose, bacteria and cells that have been sloughed off the epithelial layers if the gut. Cellulose provides bulk or fibre this helps with peristalsis and therefore bowel movements.

Questions

1.

The diagram below shows some epithelial cells from a villus in the ileum.



(a) Name the cell structure labelled A and the cell labelled B. In each case explain how they assist in the functioning of the ileum.

Cell structure A

Name ....

Function ....

....

Cell B

Name ....

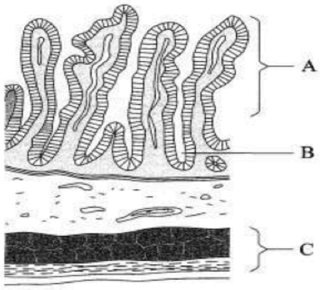
Function ....

....

(4)

2.

The diagram below shows the structure of part of the ileum wall, as seen using the low magnification of a light microscope.



Magnification ×40

(a) Name the parts labelled **A**, **B** and **C**.

A ....

B ....

C ....

(3)

(b) Explain how the part labelled **A** assists in the absorption of glucose.

....

....

....

....

....

....

....

....

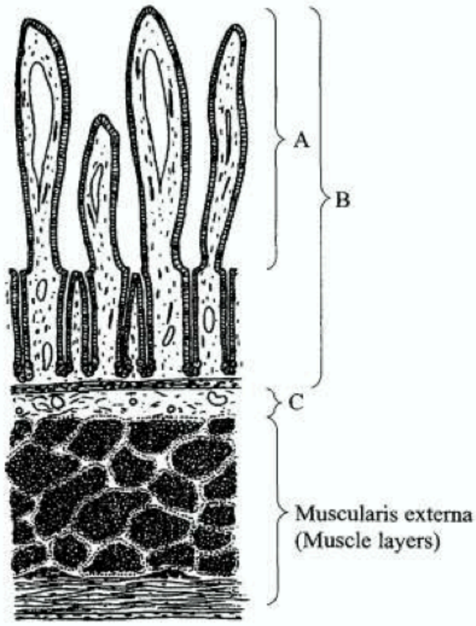
....

....

(3)

3.

The diagram below shows part of a section through the ileum, as seen under a light microscope.



(a) Name the parts labelled A, B and C.

A ....

B ....

C ....

(2)

(b) Describe the functions of the following regions of the ileum.

Part A

....

....

....

....

....

....

....

....

(4)

Muscularis externa

....

....

....

....

(2)

(Total 8 marks)

Bio Factsheet

www.curriculum-press.co.uk Number 140

Absorption in the Small Intestine

This topic appears regularly in exams of all the Boards. This is not because it is particularly difficult – in fact it's pretty straightforward - but because:

1. it can be used to illustrate the fundamental principle of the adaptation of structure to function;
2. Students keep confusing folds of the intestine with villi and microvilli. Some even refer to cilia!!

This Factsheet explains the basic principles underlying absorption and describes the commonest Questions and student errors.

Large food molecules such as proteins cannot be absorbed; they are too big and they are insoluble. Thus, digestion breaks them down into smaller and soluble molecules which can be absorbed.

90% of all absorption occurs in the small intestine, the remaining 10% occurs in the stomach and large intestine.

The first thing to do is to get an overview of what is going on. The products of digestion are absorbed across the epithelial cells of the small intestine. Substances such as **glucose** and **amino acids** then pass into the capillaries in the villi. From there they are passed to the mesenteric veins and then the hepatic portal vein which delivers them to the liver. The liver converts excess glucose into glycogen and breaks down or deaminates excess amino acids. The amine groups pass to the kidney for excretion.

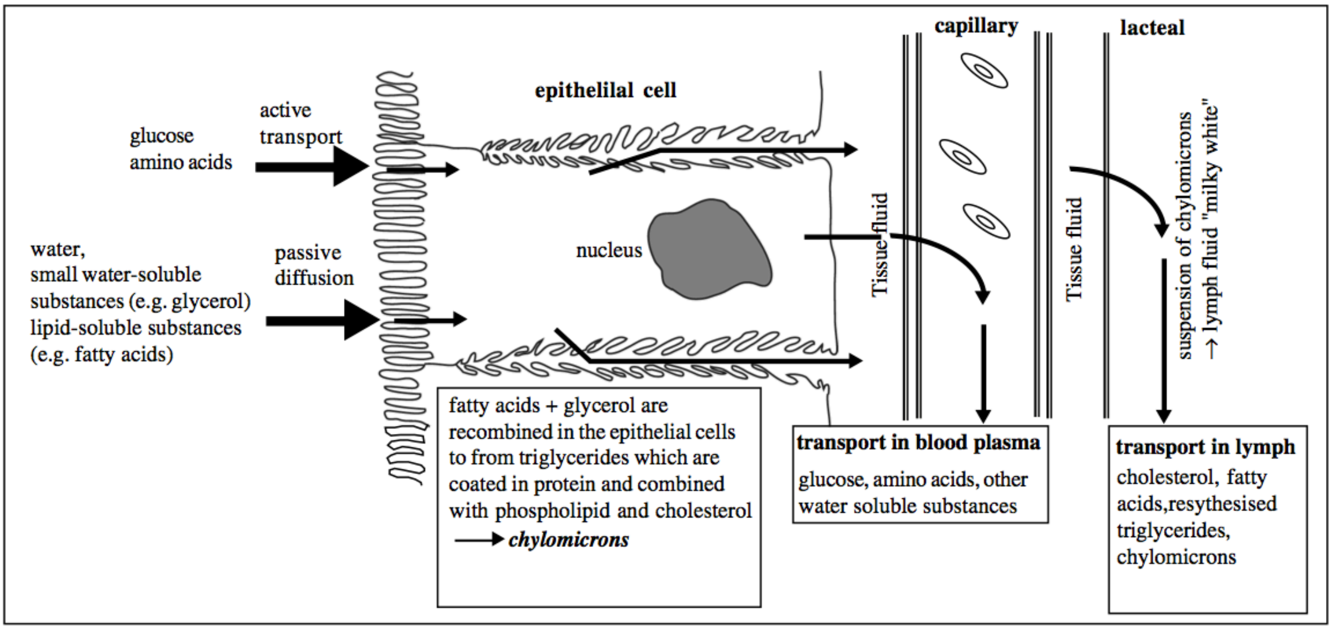
Chylomicrons (triglycerides combined with cholesterol and phospholipid) leave the epithelial cells and pass into lacteals rather than blood vessels. The lacteals eventually empty into blood vessels and once there the chylomicrons are broken back down into fatty acids and glycerol which can then enter cells for lipid synthesis.

These processes are summarised in Table 1 and Fig 2.
Fig 3. overleaf summaries all of the ways in which the small intestine is adapted for absorption. - this is the most common exam question in this topic - learn it!

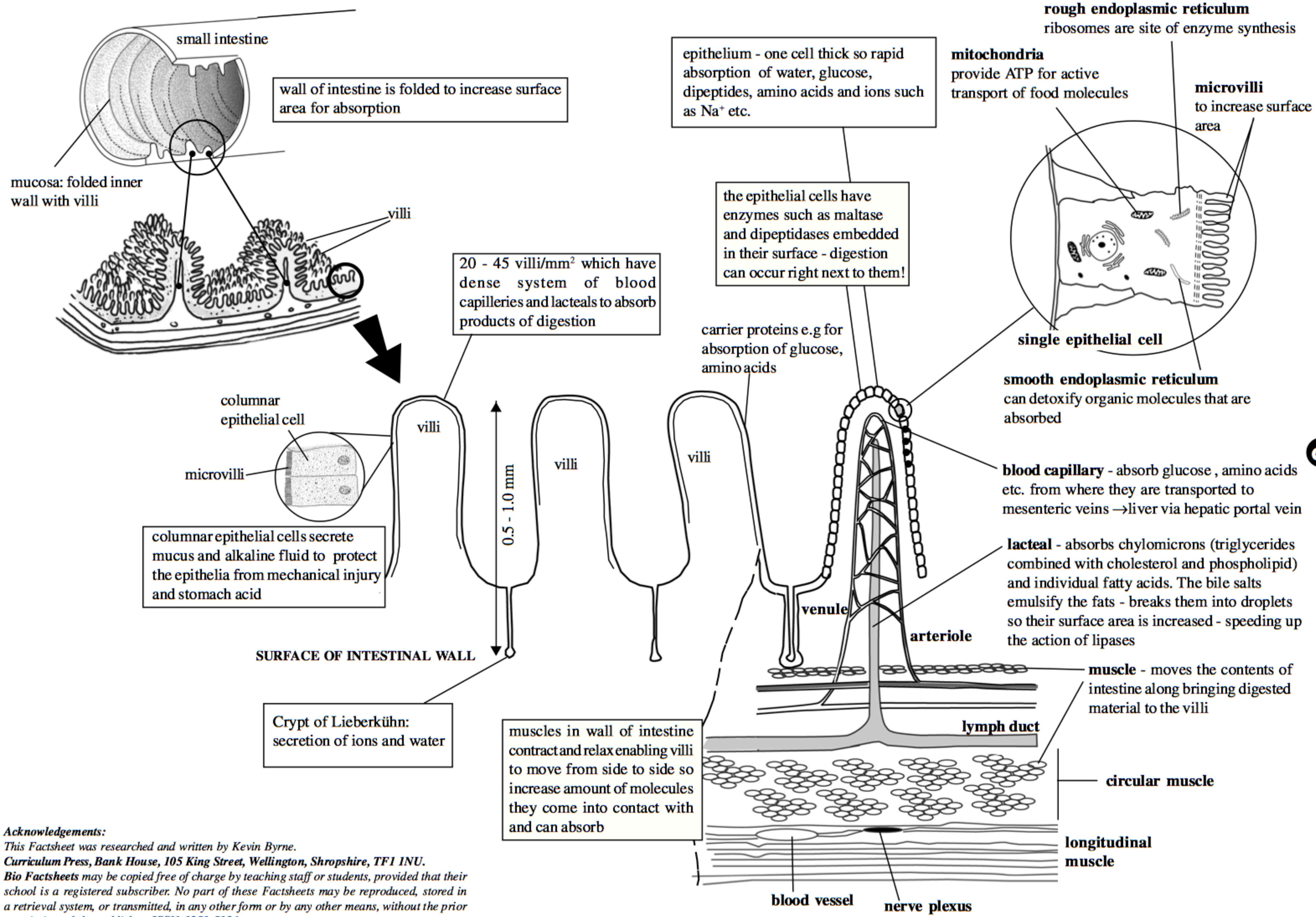
Table 1

Food substance	Absorption into epithelial cell	Absorption into blood capillary	Absorption into lacteal
Glucose	Binds to sodium and is pulled in across a carrier protein	Facilitated diffusion	
Amino acids	Binds to sodium and is pulled in across a carrier protein	Facilitated diffusion	
Short fatty acids	Diffusion	N/a	Diffusion
Long fatty acids and glycerol	Diffusion	N/a	3 fatty acids plus a glycerol molecule combine to form a triglyceride. Triglycerides combine with cholesterol and phospholipid to form chylomicrons which pass into lacteals by exocytosis

Fig 2. Absorption accross epithelial cells



Structure to function: absorption in the ileum



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Bio Factsheet

Number 24

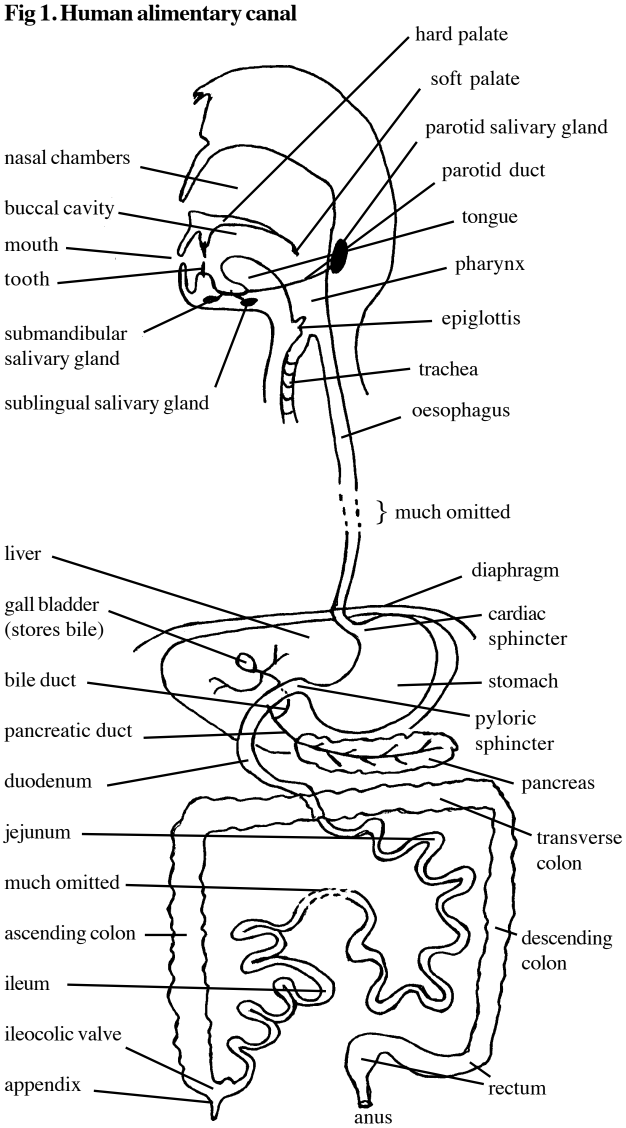
Human digestion

This Factsheet summarises the key aspects of human digestion:

1. **The gross anatomy of the human alimentary canal in relation to the processes of mastication, digestion and absorption.**
2. **The generalised histology of the gut wall and the histological structure of the oesophagus, stomach, ileum and colon in relation to the specific functions of these parts.**
3. **The sources and effects of secretions concerned with carbohydrate, protein and fat digestion.**
4. **The hormonal and nervous control of digestive secretions including olfactory and taste chemoreceptors and salivation.**
5. **The effects of alcohol on the gut.**

Examination questions on this topic often test recall knowledge of gut anatomy and histology, and of the mechanisms of digestion and absorption. Questions also often include tabular or graphical data for candidates to interpret or comment on.

Fig 1. Human alimentary canal



The gross anatomy of the human alimentary canal
The anatomy of the human digestive system can be seen in Fig 1.

The mouth is the opening to the **buccal** or oral cavity and is surrounded by muscular lips which close the mouth to retain food in the cavity. The buccal cavity is separated from the nasal chamber by the bony hard palate and cartilaginous soft palate. It contains :

1. the tongue which is made of striated voluntary muscle and this is used to mix the food with saliva and to push the food into the pharynx during swallowing.

2. the teeth which are used to masticate (chew) the food. This breaks the food up into small pieces, mixes it with saliva and breaks up the indigestible cellulose cell walls of plant material. Mastication is sometimes called mechanical digestion. The buccal cavity also receives saliva which is secreted through ducts from three pairs of salivary glands, the submandibular gland, the sublingual gland and the parotid glands (Fig 1).

The buccal cavity opens into the throat or pharynx which then continues into the food pipe or oesophagus (gullet). During swallowing, the glottis, which is the entrance to the airways, is closed by a fibrous flap of tissue known as the epiglottis. This prevents food from entering the airways.

The oesophagus carries food to the stomach by a muscular wave-like action called **peristalsis**. It joins the stomach at the cardiac sphincter. This ring of smooth muscle prevents food from regurgitating up the oesophagus when the stomach contracts. The stomach is a muscular sac which holds and churns the food with digestive gastric juice for about four hours before releasing it through the pyloric sphincter into the duodenum. The duodenum is a U-shaped tube about twelve inches long. It receives digestive secretions from the liver, called **bile**, from the pancreas, called **pancreatic juice**, and from glands in its own wall which produces a secretion called **succus entericus**.

The contents of the duodenum pass onwards into the jejunum (meaning empty, since at death the jejunus always empties into the ileum). The jejunum is about eight feet long, and the contents are held there for about twelve hours whilst digestion proceeds. The contents then pass into the ileum, which is about twelve feet long, where they remain for around twelve hours whilst absorption of nutrients into the blood and lymphatic systems occurs.

The contents are then released through the ileocolic valve into the colon. The colon is about five feet long and two and a half inches wide. It consists of the ascending, transverse and descending sections. In the colon the bulk of the remaining water and salts are absorbed into the blood, so that the contents become the consistency of faeces. Also in the colon are symbiotic bacteria, such as Escherischia coli. These are useful since they manufacture various B vitamins which are used by humans after absorption into the blood.

Eventually, the faecal material is passed into an S-shaped tube called the rectum. This is about eight inches long and when it contains faeces it causes the person to have the urge to defecate. The faecal material is evacuated to the exterior via a muscular sphincter called the anus.

The generalised histology of the gut wall

The gut wall has the same basic histological pattern throughout the alimentary canal, but the different regions of the canal have modifications in their histology related to their local functions.

The gut wall consists of distinct histological layers. Autonomic nerve plexuses lie in the base of the submucosa and in the muscularis mucosa. These are involved in regulating gut movements for moving and mixing food and digestive secretions.

Two basic types of gut movement occur, **peristalsis** and **segmentation.** Peristalsis is controlled by nervous reflex arcs from the medulla of the brain. In peristalsis, the circular muscle of the muscularis externa contracts behind the ball (bolus) of food whilst the longitudinal muscle contracts in front of the food. This constricts the gut behind the food and shortens it in front of the food. These contractions pass in waves along the gut and thus the food is forced along.

Segmentation occurs mainly in the small intestine (duodenum, jejunum, ileum) and large intestine (colon, rectum). It is a local contraction of the circular smooth muscle which divides the intestine into short segments. This helps to mix the foods and digestive juices, and to bring foods into contact with the absorptive surfaces. It is enhanced by parasympathetic stimulation and suppressed by sympathetic stimulation.

Histological specialisations of different gut regions

The oesophagus contains stratified squamous epithelium which allows it to withstand the friction of abrasive food materials passing along it. The muscles of the muscularis externa are well developed for peristalsis during swallowing. They also contain some voluntary striated muscle fibres which aid in regurgitation of food (these are particularly well developed in ruminant mammals which chew the cud).

The histology of the stomach can be seen in Fig 2. The surface epithelium is of columnar type with numerous mucous secreting goblet cells. The mucus coats the stomach wall, preventing attack by enzymes and acids. The epithelium is developed into simple tubular glands which stretch into the lamina propria. These glands contain: mucous goblet cells, chief (zymogen) cells, which secrete protein hydrolysing enzymes, oxyntic (parietal) cells which secrete hydrochloric acid and G-cells which secrete the hormone gastrin. The stomach also contains an extra layer of smooth muscle cells which run obliquely. These lie to the outside of the longitudinal muscle and give extra churning ability to enhance gastric digestion.

The histology of the ileum can be seen in Fig 3 and 4. The mucosa of the ileum is covered with millions of finger shaped projections called villi (about 0.5 to 1.0 mm high).

> ***Exam hint*** *- Structure:function of the villus is an extremely common exam question!*

Fig 2. Stomach wall lining

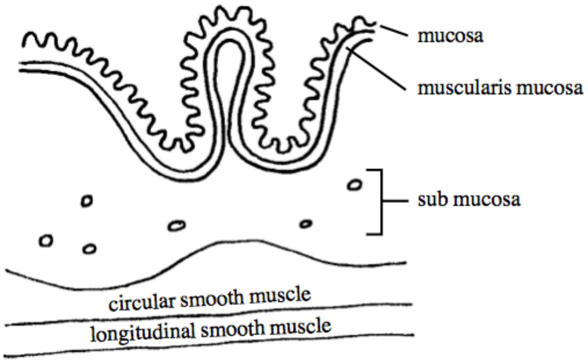


Fig 3. Epithelial cell of villus

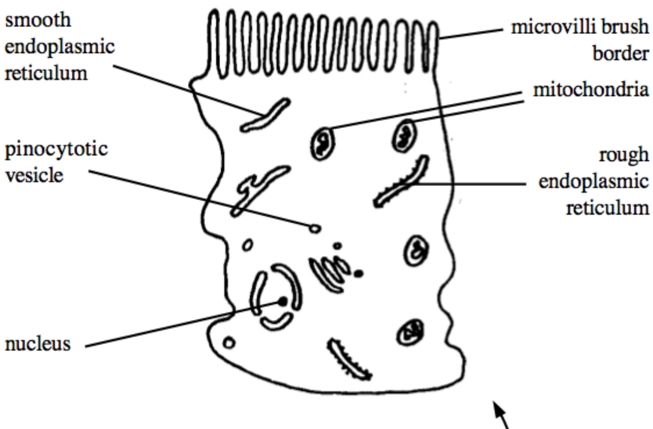
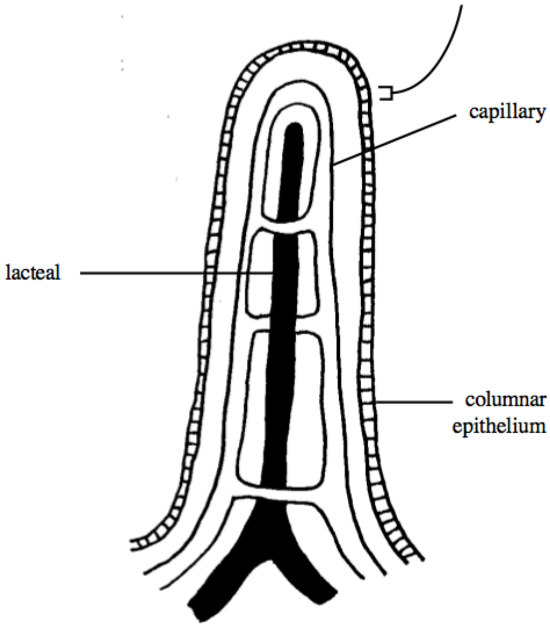


Fig 4. Histological structure of the ileum, including a villus



The **columnar epithelium** lining the villi is itself covered with microvilli which provide a huge surface area for absorption. The villi also have a superb capillary network which feeds into the hepatic portal vein to take blood and absorbed foods to the liver for assimilation, and a good lymph supply (lacteals) for fat absorption. Between the villi, the epithelium is modified into simple tubular glands which stretch into the lamina propria. These glands are the crypts of Lieberkuhn and secrete the succus entericus (intestinal digestive juice). In the duodenum, the crypts extend into the submucosa and form the glands of Brunner which secrete an alkaline mucus to protect the small intestinal wall from enzyme attack.

There are no villi present in the colon and the surface columnar epithelium absorbs water. It is extended into the lamina propria as simple tubular glands, but these secrete only mucus and do not produce enzymes. (Remember that bacteria in the colon produce many digestive enzymes to continue digestion of carbohydrates, proteins and lipids - but they do not digest cellulose in the human.) Portions of the longitudial muscles are greatly thickened and form three cords, the taenia coli, which run the length of the colon. These aid in moving contents along and in pushing faeces into the rectum when defecation becomes necessary.

Sources and effects of digestive secretions

All the digestive secretions contain water which acts as a solvent and lubricant. Most secretions also contain mucus which acts as a lubricant and also forms a protective lining over the gut surface to prevent erosion by acids and enzymes. Over-indulgence in alcohol will precipitate the mucus lining of the stomach wall, thus leaving the wall prone to erosion. The alcohol also stimulates secretion of hydrochloric acid into the stomach which can then attack the wall since the acid is fairly concentrated at pH 1.5 to 2.5. This can lead to the formation of ulcers.

The sources and effects of the digestive secretions are summarised in Table 1.

Table 1. Digestive secretions

Source	Contents	Effects
Saliva from salivary glands	Amylase	Digests starch/glycogen to maltose
Gastric juice from stomach glands	Hydrochloric acid	Provides an optimum pH for stomach enzymes. Disinfects the food. Changes inactive pepsinogen to pepsin. Promotes absorption of ions.
	Pepsinogen	Activated to pepsin which digests proteins to peptides
	Rennin	Only in babies where, together with Ca^{2+}, it coagulates milk protein to curd, making it more digestible.
	Lipase	Digests fats to fatty acids and monoglycerides
	Intrinsic factor	Promotes vitamin B12 absorption which stimulates red blood cell formation
Pancreatic juice from pancreas	Amylase	Digests starch/glycogen to maltose
	Lipase	Digests fats to fatty acids and monoglycerides
	Trypsinogen	Activated to trypsin which digests proteins to peptides and which activates chymotrypsinogen
	Chymotrypsinogen	Forms chymotrypsin which digests proteins to peptides
	Carboxypeptidase	Digests peptides to amino acids
Bile from the liver	Bile salts	Emulsifies fats into 1 micrometre droplets which increase the surface area for lipase action. Also aids the absorption of fats.
	(Bile pigments) eg. bilirubin	Breakdown products of haemoglobin which will be excreted in the faeces
Succus entericus from the crypts and Brunner's glands	Aminopeptidase	Digests peptides to amino acids
	Maltase	Digests maltose to glucose
	Sucrase	Digests sucrose to glucose and fructose
	Lactase	Digests lactose to glucose and galactose
	Enterokinase	Activates trypsinogen to trypsin

Note that many of the enzymes are secreted in an inactive form. This is to protect against self-digestion when the enzymes are actually inside their glands.

The control of digestive secretions

Saliva is released continuously in small volumes but more is released for feeding. The release from the salivary glands is under **parasympathetic** nervous control and is stimulated by the thought, smell, sight and taste of food, by the presence of food in the buccal cavity and by chewing. The taste receptors are in taste buds in the epithelium over the tongue and cheeks, and the olfactory receptors are in the nasal mucosa.

Gastric juice secretion is also initiated by parasympathetic stimulation through the vagus nerve which is stimulated by the smell, sight, taste of food and by the presence of food in the buccal cavity. Once food is in the stomach, the release of gastric juice is enhanced by the action of the hormone gastrin from the G-cells of the gastric glands. The flow of gastrin can also be stimulated by the presence of caffeine or alcohol in the stomach and by a reduced blood glucose concentration. Eventually the gastrin stimulates the pyloric sphincter to relax momentarily, thus releasing a small volume of acidic chyme (the stomach contents after gastric digestion) into the duodenum. The presence of acid chyme in the duodenum causes nerve impulses to pass to the medulla of the brain. These then pass out through the parasympathetic vagus nerve to stimulate:

1. the flow of bile from the liver and gall bladder
2. release of pancreatic juice from the pancreas
3. cells in the duodenal glands to release (a) **cholecystikinin** which stimulates the release of more bile and pancreatic juice and (b) **secretin** which stimulates the release of more intestinal and pancreatic juice.

The secretion of gastrin is switched off, the pyloric sphincter opens for longer periods and the stomach contracts to empty its chyme into the duodenum. When the stomach is empty the pyloric sphincter closes. After digestion and absorption in the small intestine, cells in its wall secrete more gastrin which causes the ileocolic valve to relax and the small intestine muscles to become more active. Thus the chyle (contents of the small intestine after digestion) is forced into the ascending colon. The release of the intestinal hormones is then switched off.

Absorption of digested products

This occurs mainly via the villi in the small intestine, although the colon also absorbs water, electrolytes and vitamins.

In the small intestine, water is absorbed into the blood osmotically, salts and vitamins are absorbed into the blood by diffusion or active transport, and monosaccharides, amino acids and short chain fatty acids are absorbed into the blood mainly by active transport. Long chain fatty acids and monoglycerides are absorbed as micelles, resynthesised to trigycerides which form chylomicrons. These are transferred into the lacteals. Glucose, galactose and sodium ions are all actively transported into the epithelium of the villus by the same carrier molecule which has receptor sites for all three substances. All three receptors must be filled before the transport can occur. Thus glucose cannot be absorbed efficiently in the absence of sodium or galactose. Fructose is absorbed by facilitated diffusion (this uses a carrier but does not require the expenditure of energy). These monosaccharides then move from the epithelium into the blood by facilitated diffusion.

Amino acids are also absorbed into the epithelium by active transport. They then enter the blood stream by diffusion. Short chain fatty acids (less than 10 carbons long) enter the epithelium and then the blood by simple diffusion.

Bile salts form spherical micelles about 25nm in diameter. Each micelle contains about 50 bile salt molecules and is soluble in water. Long chain fatty acids and monoglycerides will dissolve into the centre of the micelles which then ferry the lipids to the epithelial surface of the villi. The fatty acids and monoglycerides then diffuse into the epithelial cells, leaving the micelles behind to carry out further ferrying. In the epithelial cells, the fatty acids and monoglycerides recombine to form triglycerides. These associate with cholesterol and phospholipids and are then coated with proteins to form chylomicrons. These pass into the lacteals of the villi to be transported via the lymph.

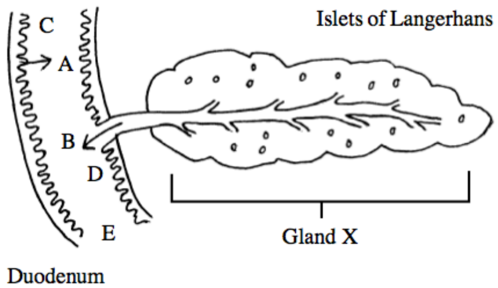
Practice questions

1. Complete the following passage by inserting the most suitable word or words into the spaces:

   After a few hours of digestion in the stomach, the ______________ relaxes, momentarily allowing a small quantity of acid ______________ to be released into the ______________. This stimulates the gut wall to release two hormones, cholecystikinin and ______________, which stimulates the flow of ______________.

   (6 marks)

2. The diagram below shows part of the human digestive system:



   (a) Name gland X as shown on the diagram (1 mark)

   (b) Name secretions A and B (2 marks)

   (c) These secretions contain enzymes concerned with the digestion of carbohydrates. Name **two** such enzymes present in A and **one** such enzyme present in B. (3 marks)

Answers

Marking points are shown by semicolons

1. pyloric sphyncter;
   chyme;
   duodenum;
   secretin;
   intestinal juice/pancreatic juice;

2. (a) pancreas;

   (b) A = intestinal juice (succus entericus);
   B = pancreatic juice;

   (c) A = Maltase;
   Lactase;
   Sucrase;

   B = Amylase

Acknowledgements;
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